Single Event Transients in LT1128 operational amplifier Heavy ion test report

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Table of Contents

1 Introduction

This report presents Single Event Transient (SET) test data on the LT1128 operational amplifier from Linear Technology. These tests were performed in the frame of the NEPP/Single Event Transient in linear devices study.

2 Tested Devices

The tested devices are described in Table 1.

Type	**LT1128**
Manufacturer	Linear Technology
Function	High speed operational Amplifier
Package	DIP8
Package marking	0050C LT1128 CN8
Previous SEE testing	No data is available in the literature

Table 1: description of the tested device.

3 Irradiation facility

Heavy ion irradiations were performed at TEXAS A&M in December 2002. Irradiations were performed in Air. The distance of Air between the 25.4 µm Aramica beam window and the Device under test is 5 cm. The types of ions used and their energy is given in Table 2.

Ion Type	Ion Energy (MeV)	LET on target (MeVcm2/mg)	Range on target (µm)
Ne	266	2.8	262
Ar	496	8.7	174
Kr	912	29.3	116
Xe	1291	53.9	102

Table 2: Characteristics of ions used during the experiments in December 2002.

4 Test set-up and bias condition

Three different applications conditions have been investigated:

- Non Inverting Gain amplifier2 (x11),
- Voltage Follower.

The bias conditions are shown in Figures 1 and 2. The device output is monitored by an oscilloscope. As soon as the device output deviates of more than 500 mV from the nominal output, a transient is counted and the transient frame is stored for further analysis. The DUT is connected to the oscilloscope with an active FET probe.

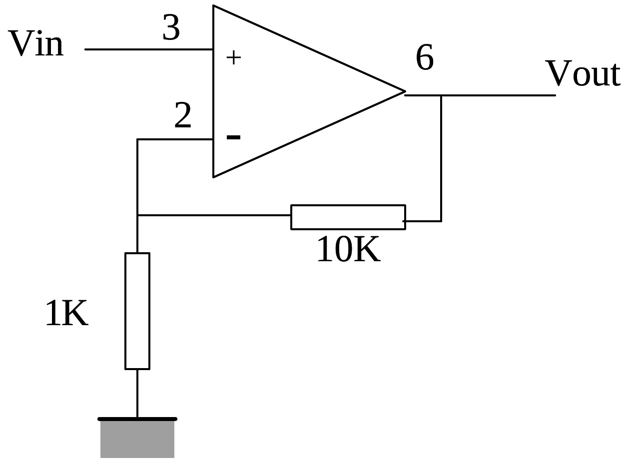


Figure 1: Non Inverting Gain x11 bias conditions.

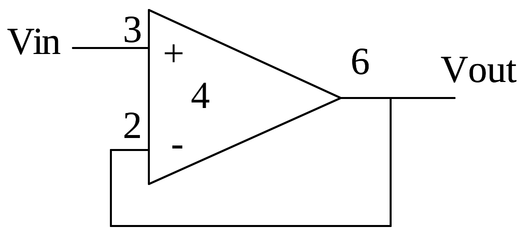


Figure 2: Voltage Follower bias conditions

The tested input bias conditions are described in Table 3. All the experiments were performed for a nominal power supply voltage of +/-15V.

Application	Input (V)	Output (V)
Voltage follower	1	1
	5	5
	10	10
Non inverting gain x11	0.1	1.1
	0.5	5.5
	1	11

Table 3: Input bias conditions

5 Test Results

5.1 SET cross section curve

Figure 3 shows the SET cross section curve. The detailed results are shown in the Tables in Appendix1. The application and input bias conditions do not have an effect on the overall cross section curves. The lower cross sections obtained for the highest input voltages, voltage follower with Vin=10V and non-inverting gain with Vin=1V, were due to a different trigger threshold setting of the oscilloscope. For these conditions the trigger threshold was set at 1V instead of 500 mV for the other conditions.

The application, bias, and irradiation conditions have a significant effect on the transient waveforms as detailed in the following section.

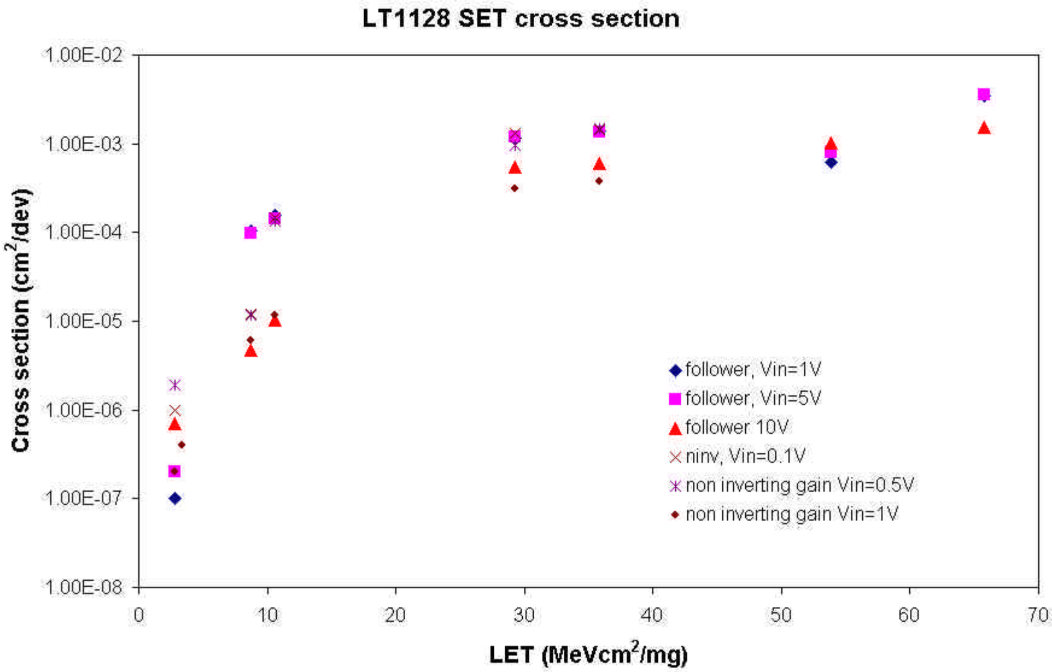


Figure 3: LT1128, SET cross section curve

5.2 Transient waveform analysis

Ten different transient waveforms were observed:

- class A: large amplitude positive going transients,
- class B: small amplitude, short duration negative going transients,
- class C: small amplitude, short duration positive going transients,
- class D: long duration oscillating waveform,
- class E: oscillating waveform starting with a large negative going component,
- class F: large amplitude negative going transients,
- class G: small amplitude, short duration oscillating waveform starting with a short negative going component,
- class H: small amplitude, short duration oscillating waveform starting with a positive going component,,
- class I: long duration oscillating waveform starting like a class F transient,
- class J: long duration oscillating waveform starting like a class E transient.

Typical transient waveforms for each of these classes are shown in Figure 4 to 13.

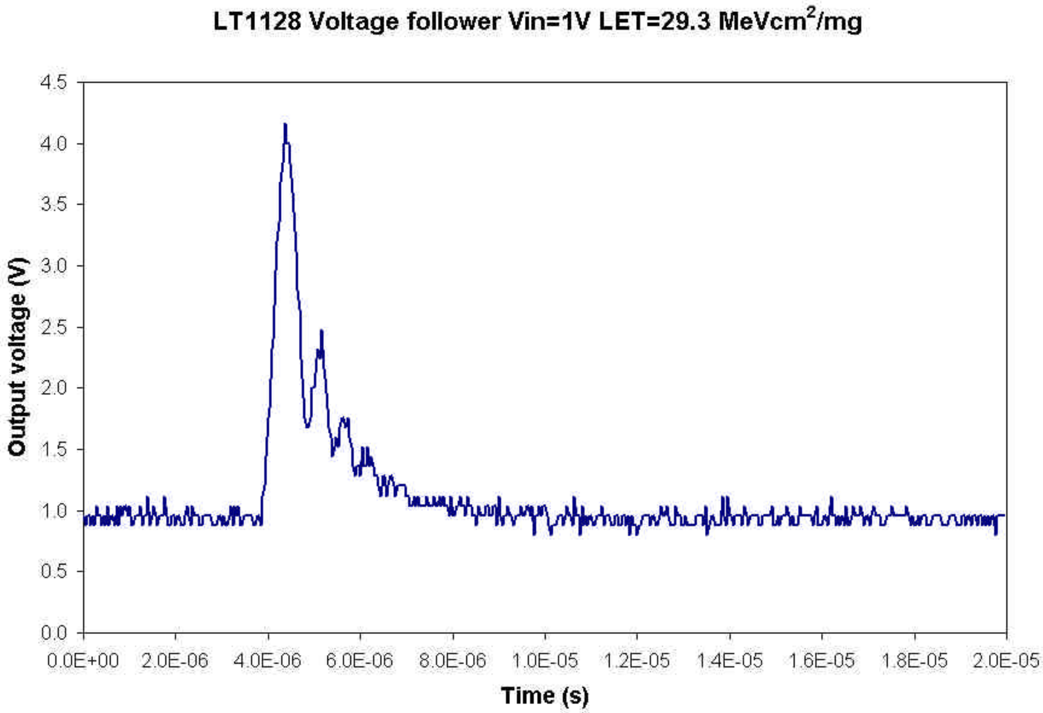


Figure 4: Examples of class A SETs

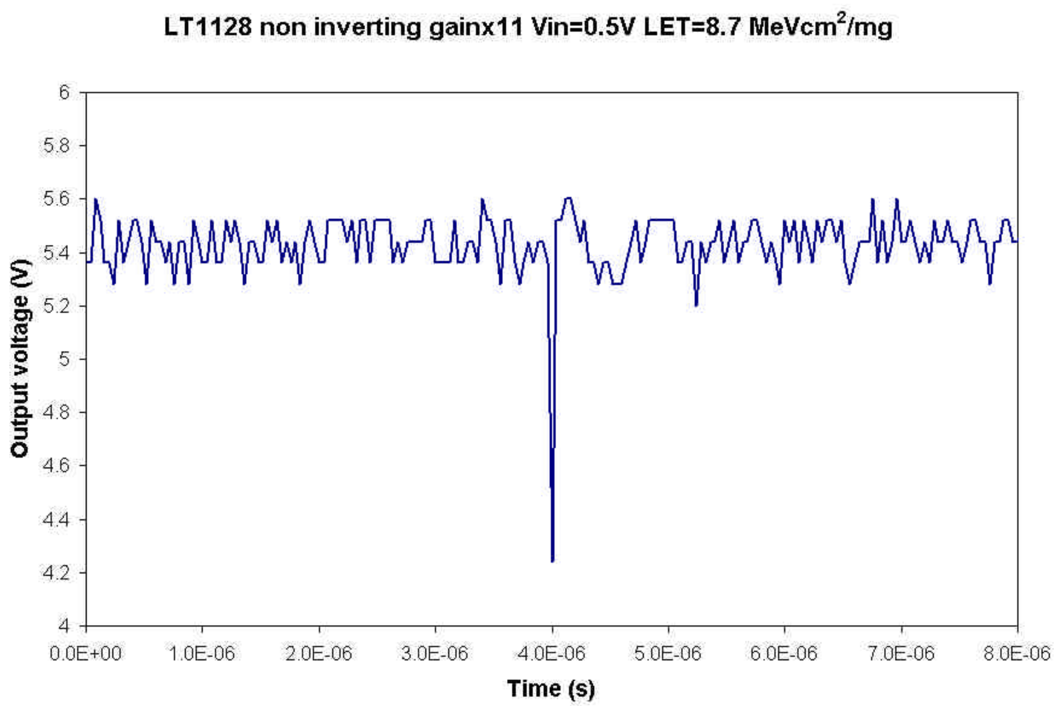


Figure 5: Examples of class B SETs

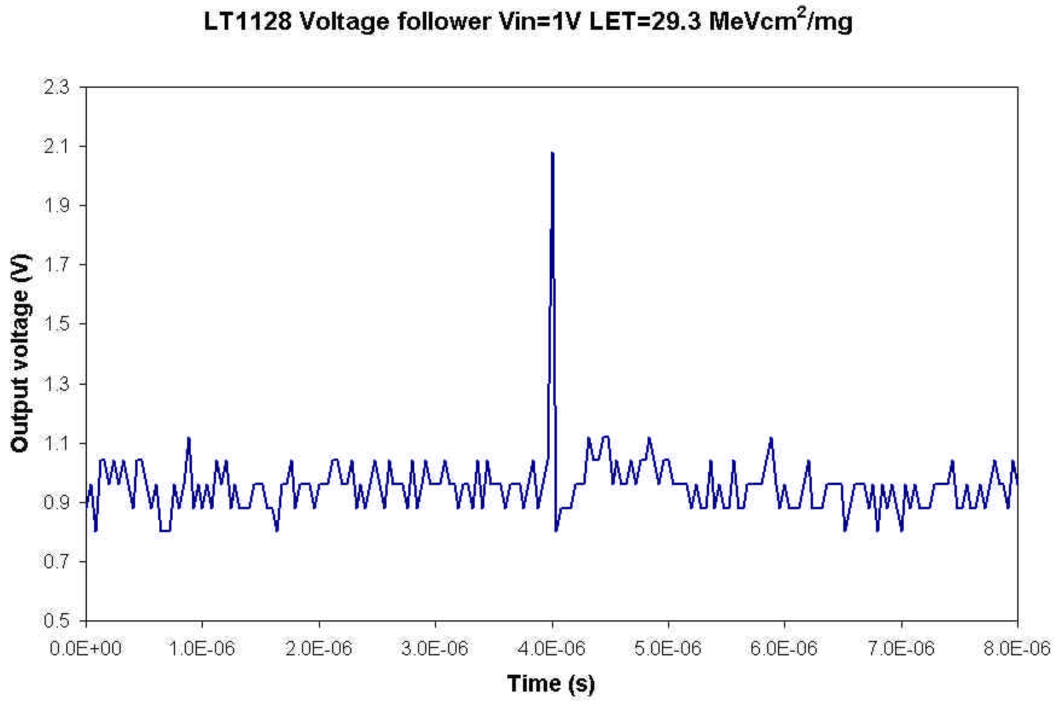


Figure 6: Examples of class C SETs

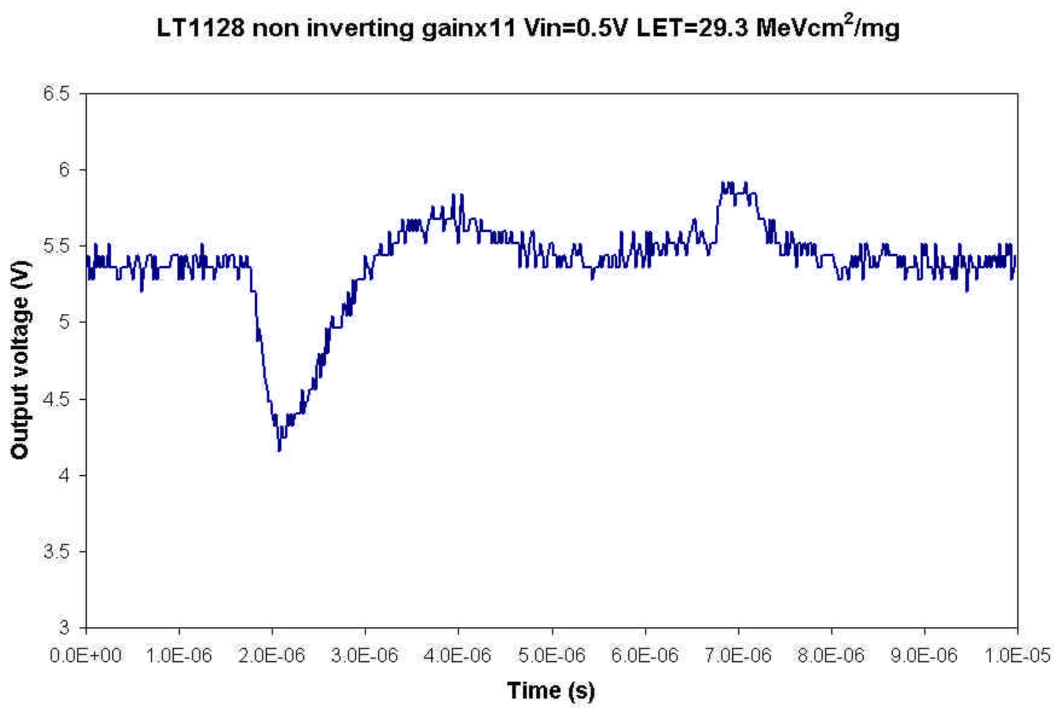


Figure 7: Examples of class D SETs

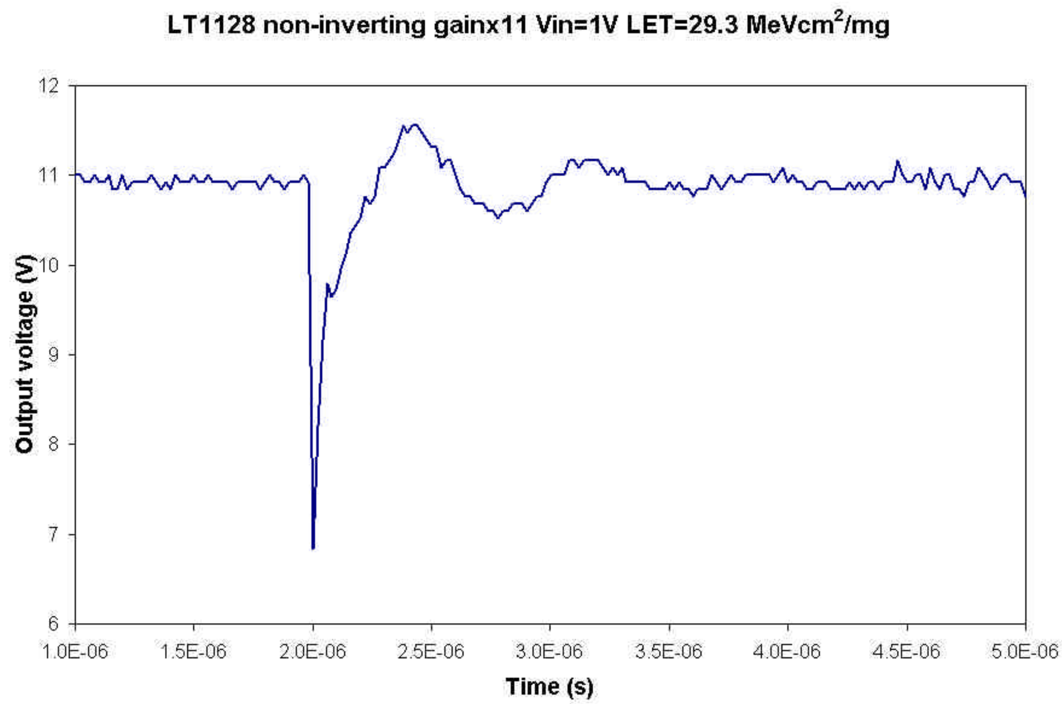


Figure 8: Examples of class E SETs

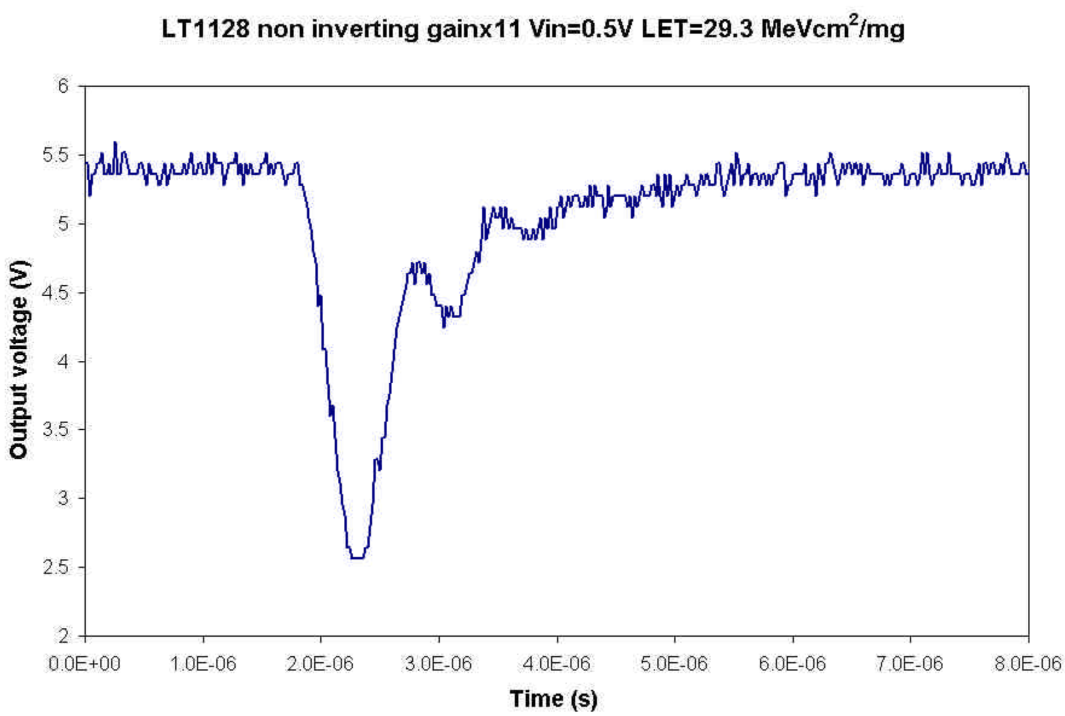


Figure 9: Example of class F SETs

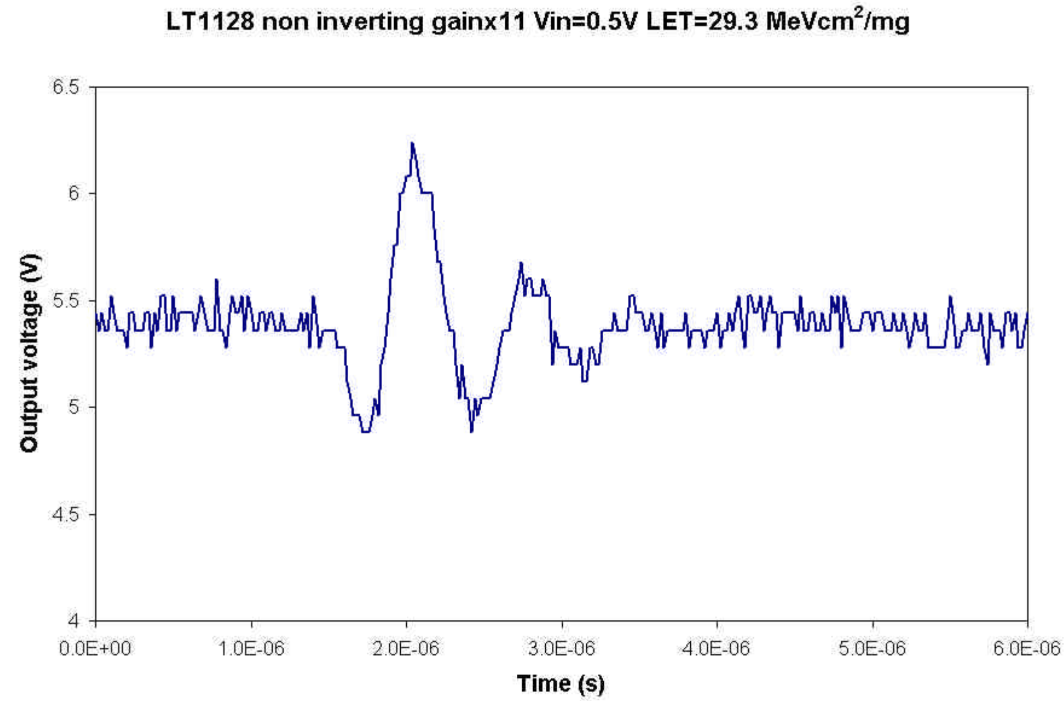


Figure 10: Examples of class G SETs

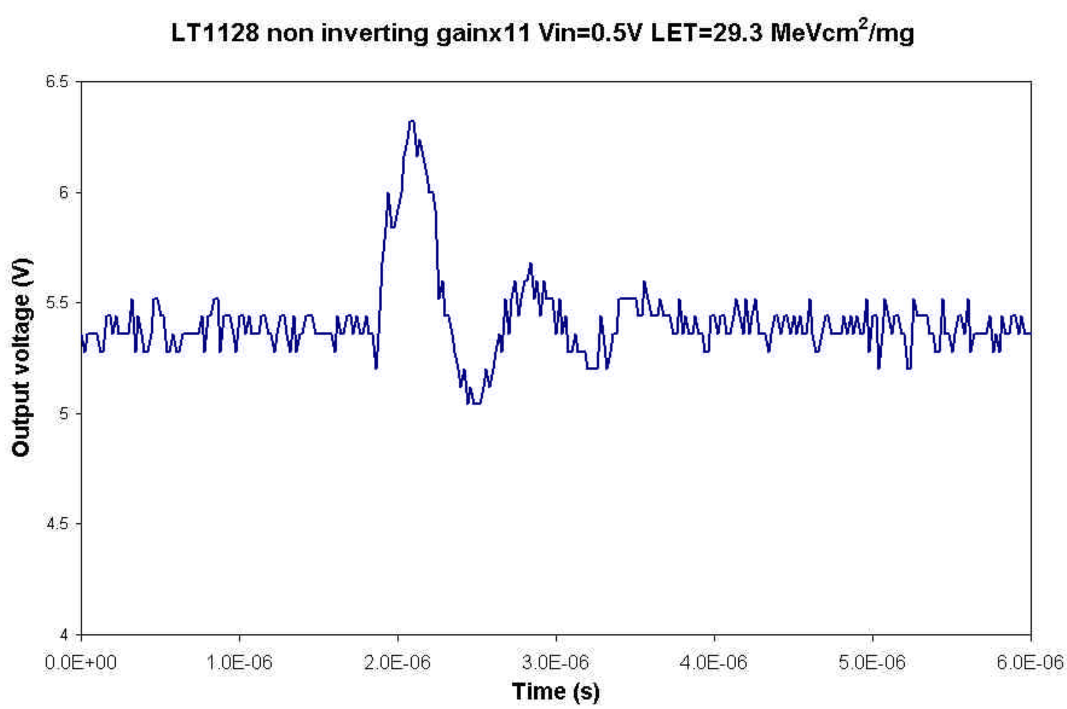


Figure 11: Examples of class H SETs

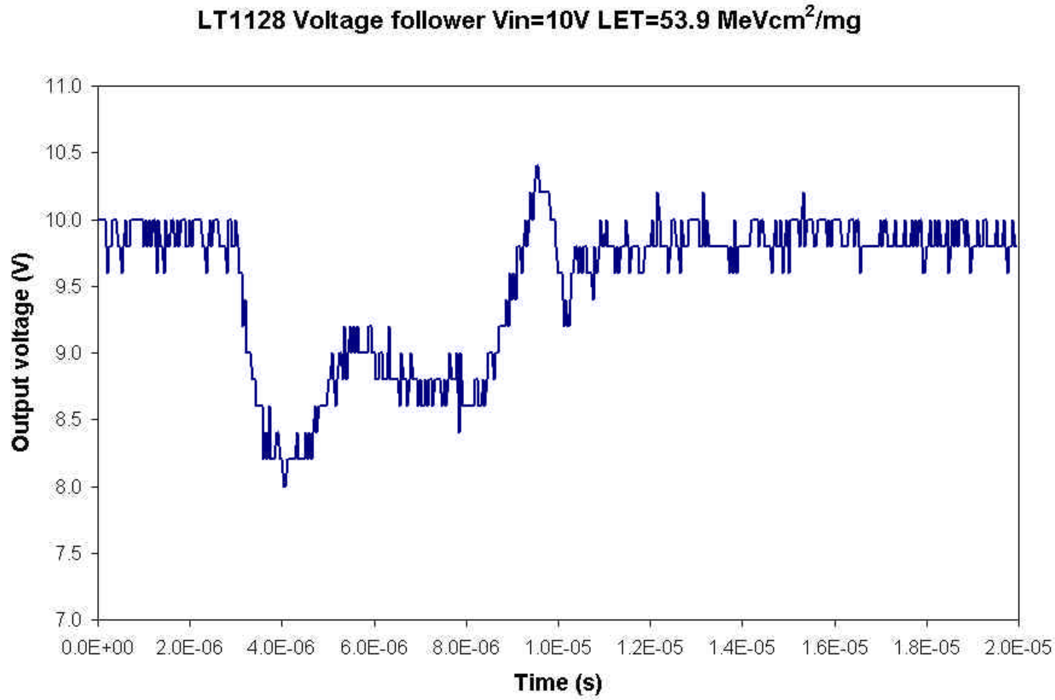


Figure 12: Examples of class I SETs

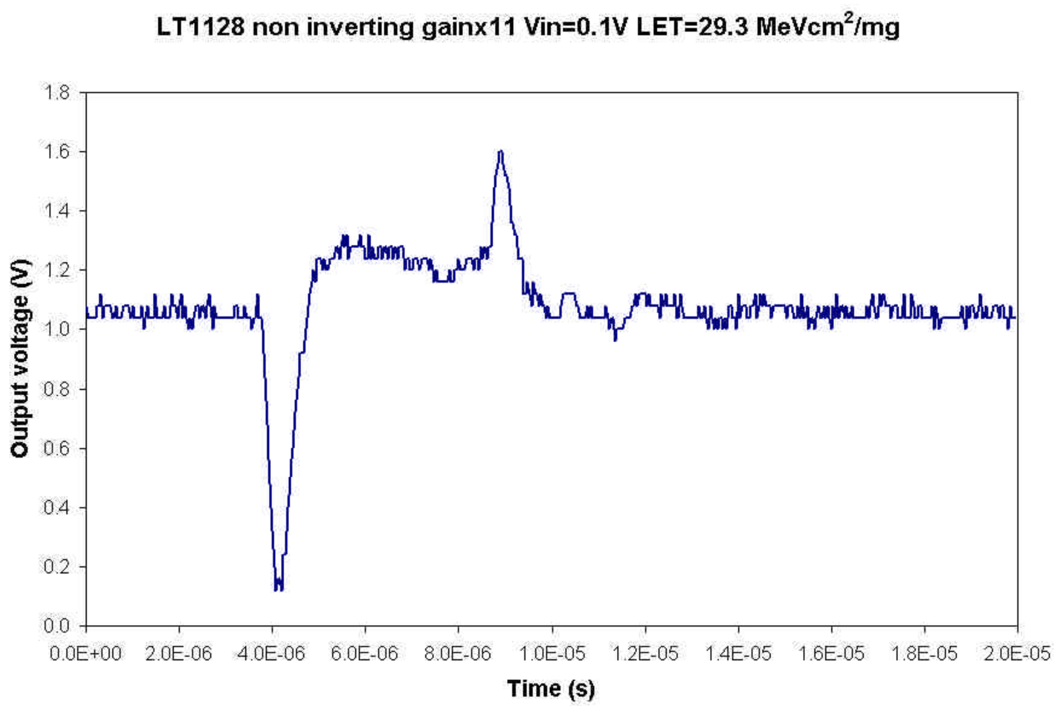


Figure 13: Example of class J SETs

The transients' widths versus amplitude were plotted for the different test conditions investigated. We identified the transient class in these plots. The amplitude is defined as the maximum transient amplitude, and the width as the Full width at Half Maximum (FWHM). For the oscillating waveforms; classes D, E, G, H, I, and J; we have plotted the largest amplitude component. These plots are shown in Appendix 2.

The amplitude versus width plots show the contribution of each transient class to the total device's response:

- class E transients were observed for all test conditions and all LET values. They are a significant part of the device's total response. Their maximum amplitude is 5V, and their maximum total duration is less than 1 μs.
- class A transients appear at the LET of 8.7 MeVcm^2/mg. They dominate the device's total response for the voltage follower application, but they are quasi non-existent in the non-inverting gain application. Their maximum amplitude is 5V, and their maximum total duration is less than 2 μs.
- class F transients appear at the LET of 8.7 MeVcm^2/mg. They dominate the device's total response for the non-inverting gain application, but they do not appear in the voltage follower application. Their maximum amplitude is 5V, and their maximum total duration is less than 2 μs.
- class C transients appear at the LET of 8.7 MeVcm^2/mg. They represent a significant part of the device's total response. Their maximum amplitude is 5V, and their maximum total duration is less than 100 ns.
- class B transients appear at the LET of 8.7 MeVcm^2.mg. class B transients are marginal in the non-inverting gain application. Their maximum amplitude is 5V, and their maximum total duration is less than 100 ns.
- Class D transient appear at the LET of 29.3 MeVcm^2/mg. Class D transients were not observed in the voltage follower application with a 10V input and the non-inverting gain configuration with 1V input. When they appear, they appear in small numbers but still represent a significant part of the device's total response. Their maximum amplitude is 1V, and their maximum total duration is less than 10 μs.

All the other transient classes represent a marginal part of the device total response:

- class G transients appear at the LET of 8.7 MeVcm^2/mg . Their maximum amplitude is 2V, and their maximum total duration is less than 2 μs.
- class H transients appear at the LET of 29.3 MeVcm^2/mg. Their maximum amplitude is 2V, and their maximum total duration is less than 2 μs.
- class I transients only appear in the voltage follower application with a 10V input voltage at the highest LET of 53.9 MeVcm^2/mg. Their maximum amplitude is 3V, and their maximum total duration is less than 10 μs.
- class J transients only appear in the non-inverting gain application with a 0.1V input voltage at the highest LET of 29.3 MeVcm^2/mg. Their maximum amplitude is 3V, and their maximum total duration is less than 12 μs.

6 Conclusion

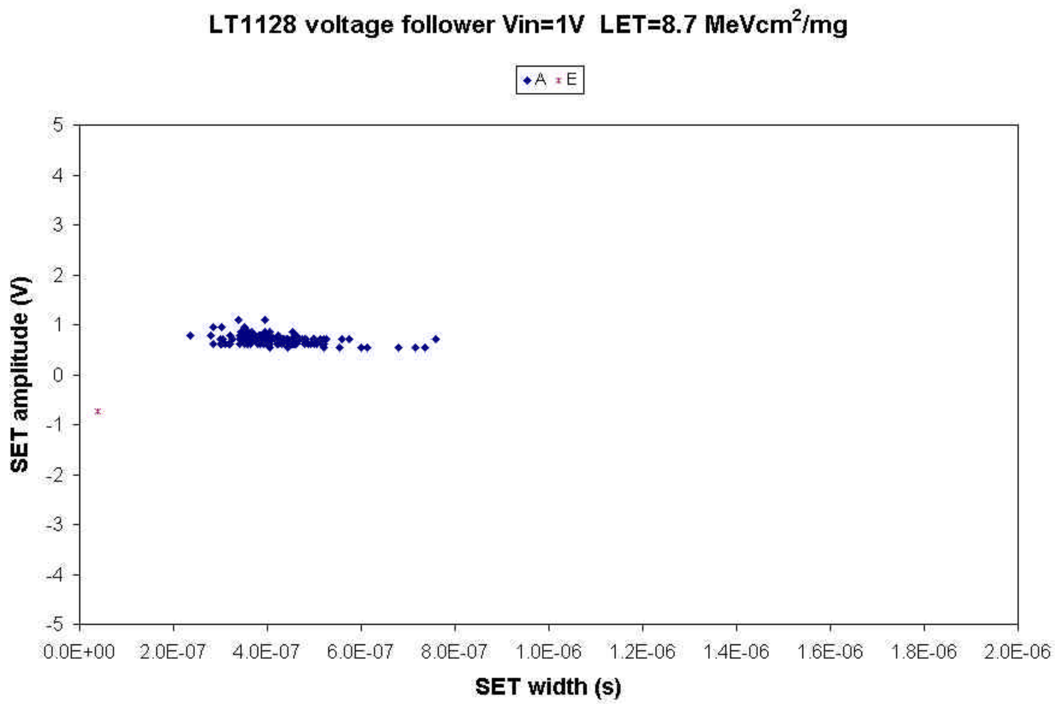
This report presents the SET heavy ion test data on the LT1128 operational amplifier. A large variety of transients was observed. We cannot see a significant effect of the application and bias conditions on the SET cross section curves., but the application and bias conditions have an effect on the SET characteristics. For example, the dominant transient class in the voltage follower application is quasi non-existent in the non-inverting gain application. And, the dominant transient class in the non-inverting gain application is non existent in the voltage follower application.

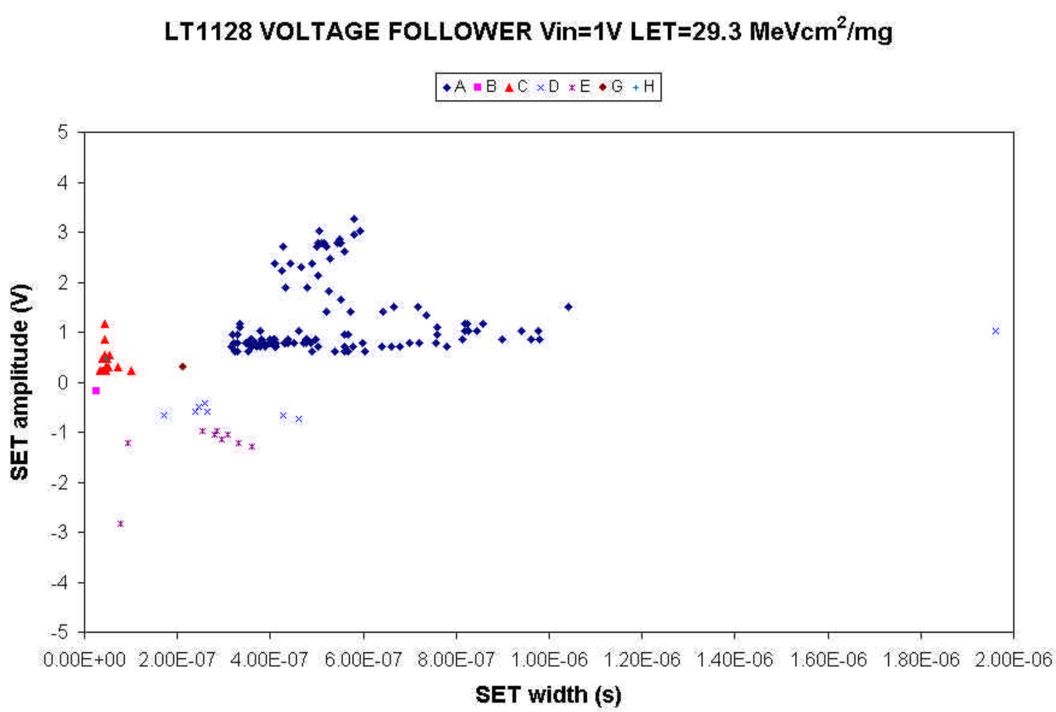
The results also show that in high-speed operational amplifiers, a lot of transients have oscillating waveforms. The largest transients have a 5V amplitude and a duration lower than 1 µs. The longest transients have a duration of 10 us but the amplitude is less than 10V. These characteristics make these transients easy to filter when filtering is a possible mitigation option.

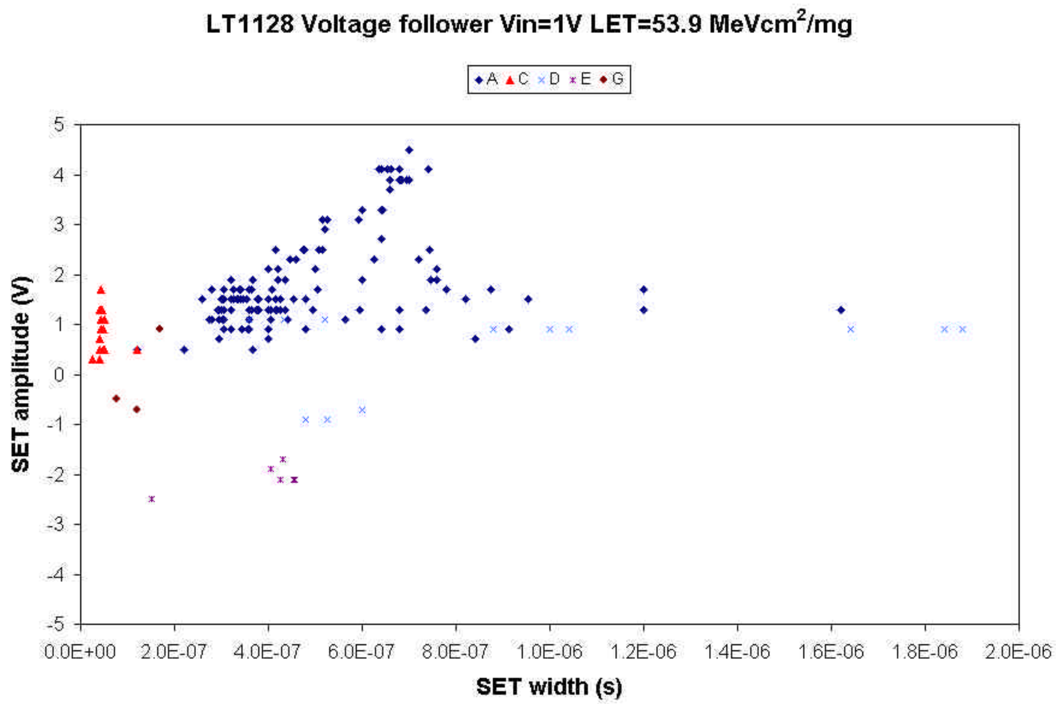
7 Appendix 1: Detailed test results

Run #	Application	Vin (V)	SN #	Ion	Energy (MeV)	LET (MeVcm^2/mg)	Tilt (º)	eff. LET (MeVcm^2/mg)	eff. Fluence (#/cm^2)	SET #	X SET (cm^2/dev)	comment
37	follower	1	1	Xe	1291	53.90	0	53.90	3.34E+05	204	6.11E-04	trigger=0.5/1.5V
38	follower	5	1	Xe	1291	53.90	0	53.90	3.37E+05	268	7.95E-04	trigger=4.5/5.5V
39	follower	10	1	Xe	1291	53.90	0	53.90	2.27E+05	229	1.01E-03	trigger=9.5/11V
40	follower	10	1	Xe	1291	53.90	35	65.80	1.39E+05	211	1.52E-03	
41	follower	5	1	Xe	1291	53.90	35	65.80	7.16E+04	258	3.60E-03	trigger=4.5/5.5V
42	follower	1	1	Xe	1291	53.90	35	65.80	9.15E+04	319	3.49E-03	trigger=1.5/2.5V
44	follower	1	1	Kr	912	29.30	0	29.30	1.84E+05	211	1.15E-03	
45	follower	5	1	Kr	912	29.30	0	29.30	1.75E+05	209	1.19E-03	trigger=4.5/5.5V
47	follower	10	1	Kr	912	29.30	0	29.30	3.79E+05	204	5.38E-04	trigger=9.5/11V
48	follower	10	1	Kr	912	29.30	35	35.80	3.40E+05	203	5.97E-04	
49	follower	5	1	Kr	912	29.30	35	35.80	1.53E+05	207	1.35E-03	
50	follower	1	1	Kr	912	29.30	35	35.80	1.91E+05	266	1.39E-03	
103	follower	1	1	Ar	496	8.69	0	8.69	1.95E+06	204	1.05E-04	
104	follower	5	1	Ar	496	8.69	0	8.69	2.06E+06	204	9.90E-05	
105	follower	10	1	Ar	496	8.69	0	8.69	1.00E+07	47	4.70E-06	
106	ninv	0.1	2	Ar	496	8.69	0	8.69	1.00E+07	119	1.19E-05	
107	ninv	0.5	2	Ar	496	8.69	0	8.69	1.00E+07	116	1.16E-05	
108	ninv	1	2	Ar	496	8.69	0	8.69	1.00E+07	61	6.10E-06	
109	ninv	1	2	Ar	496	8.69	35	10.60	1.00E+07	117	1.17E-05	
111	ninv	0.5	2	Ar	496	8.69	35	10.60	1.85E+06	245	1.32E-04	
112	ninv	0.1	2	Ar	496	8.69	35	10.60	1.44E+06	212	1.47E-04	
113	follower	1	1	Ar	496	8.69	35	10.60	1.31E+06	205	1.56E-04	
114	follower	5	1	Ar	496	8.69	35	10.60	1.63E+06	230	1.41E-04	
118	follower	10	1	Ar	496	8.69	35	10.60	5.83E+05	231	3.96E-04	tried trigger=10V, device output<10V
119	follower	10	1	Ar	496	8.69	35	10.60	1.00E+07	102	1.02E-05	trigger=9.5/11V
120	follower	10	1	Ne	266	2.78	0	2.78	1.00E+07	*7*	7.00E-07	
121	follower	5	1	Ne	266	2.78	0	2.78	1.00E+07	2	2.00E-07	trigger=4.5/5.5V
122	follower	1	1	Ne	266	2.78	0	2.78	1.00E+07	1	1.00E-07	trigger=0.5/1.5V
124	ninv	0.1	2	Ne	266	2.78	0	2.78	1.00E+07	10	1.00E-06	trigger=0.6/1.6V
125	ninv	0.5	2	Ne	266	2.78	0	2.78	1.00E+07	19	1.90E-06	trigger=5/6V
126	ninv	1	2	Ne	266	2.78	0	2.78	1.00E+07	2	2.00E-07	trigger=10/12V
127	ninv	1	2	Ne	266	2.78	35	3.39	1.00E+07	4	4.00E-07	
147	ninv	0.1	2	Kr	912	29.30	0	29.30	1.64E+05	213	1.30E-03	trigger=0.6/1.6V
150	ninv	0.5	2	Kr	912	29.30	0	29.30	2.08E+05	201	9.66E-04	trigger=5/6V
151	ninv	1	2	Kr	912	29.30	0	29.30	6.47E+05	200	3.09E-04	trigger=10/12V
152	ninv	1	2	Kr	912	29.30	0	29.30	2.01E+05	200	9.95E-04	trigger 10.5/11.5V
153	ninv	1	2	Kr	912	29.30	35	35.80	5.47E+05	204	3.73E-04	trigger 10/12
154	ninv	0.5	2	Kr	912	29.30	35	35.80	1.40E+05	210	1.50E-03	trigger 5/6V
155	ninv	0.1	2	Kr	912	29.30	35	35.80	1.41E+05	204	1.45E-03	trigger 0.6/1.6

8 Appendix 2 : Transients' width versus amplitude plots



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SET amplitude (V)
SET width (s)
5
4
3
2
1
0
-1
-2
-3
-4
-5
0.0E+00
2.0E-07
4.0E-07
6.0E-07
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1.0E-06
1.2E-06
1.4E-06
1.6E-06
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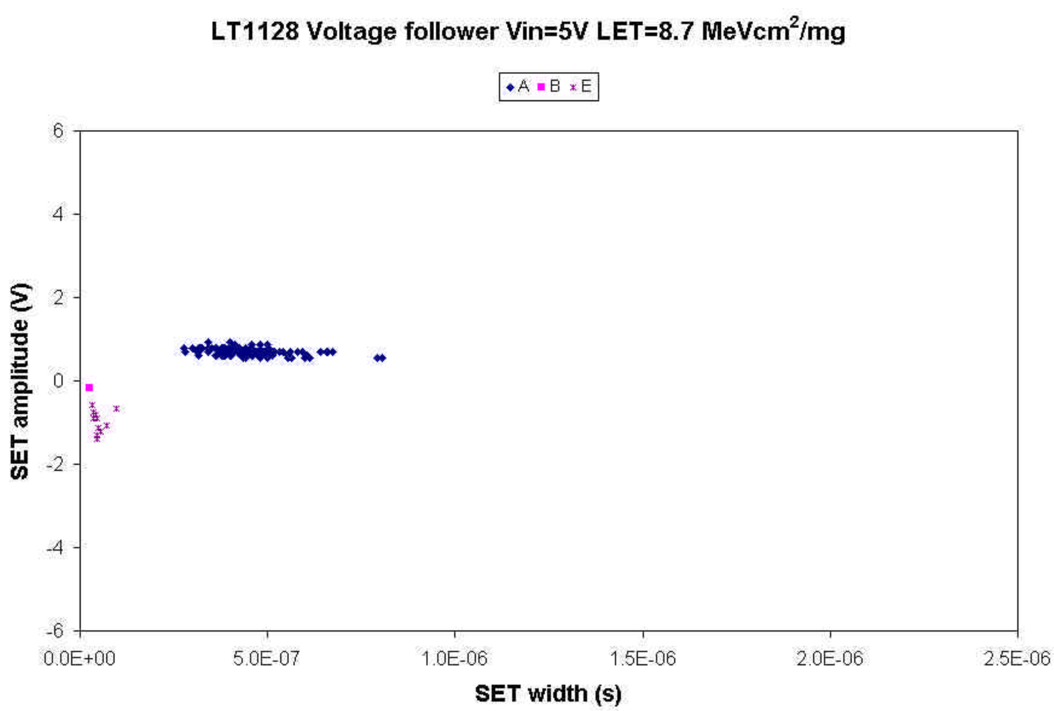
2.0E-06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A B E
SET amplitude (V)
SET width (s)
6
4
2
0
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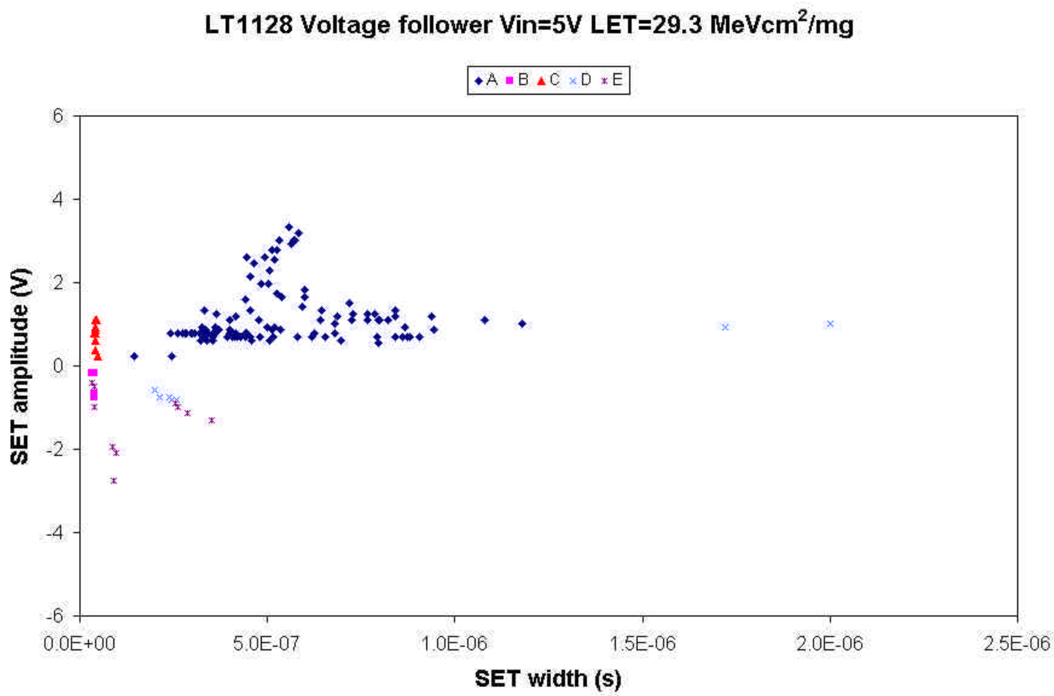
-4
-6
0.0E+00
5.0E-07
1.0E-06
1.5E-06
2.0E-06
2.5E-06



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4
2
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-6
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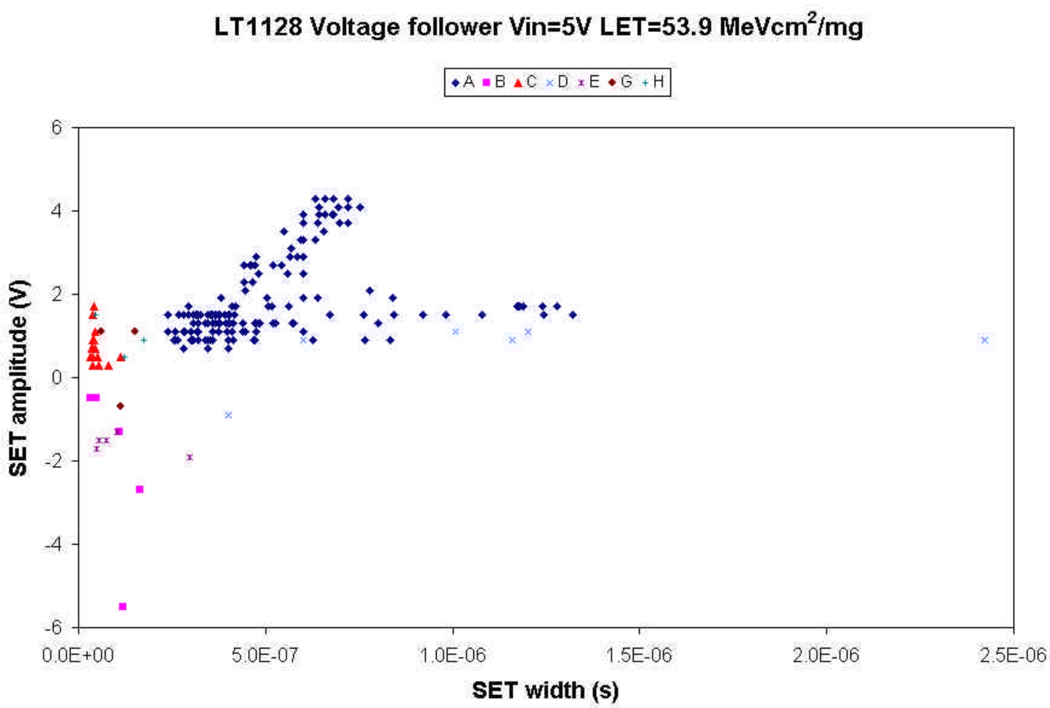
1.5E-06
2.0E-06
2.5E-06



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4
2
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-2
-4
-6
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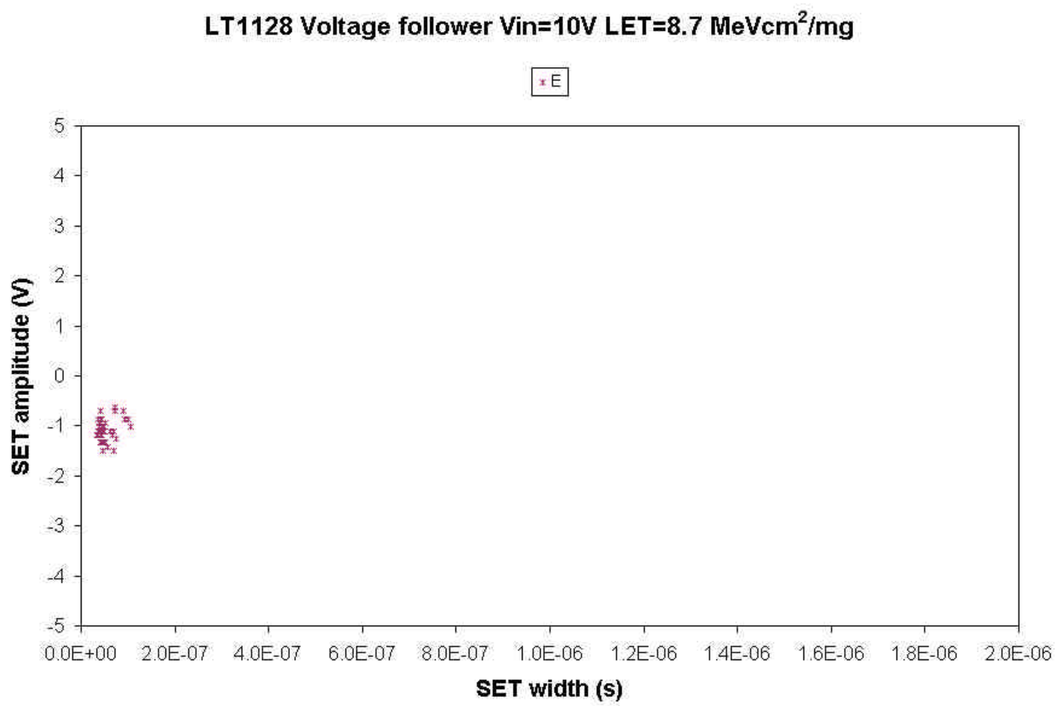
5.0E-07
1.0E-06
1.5E-06
2.0E-06
2.5E-06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3
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-2
-3
-4
-5
0.0E+00
2.0E-07
4.0E-07
6.0E-07
8.0E-07
1.0E-06
1.2E-06
1.4E-06
1.6E-06
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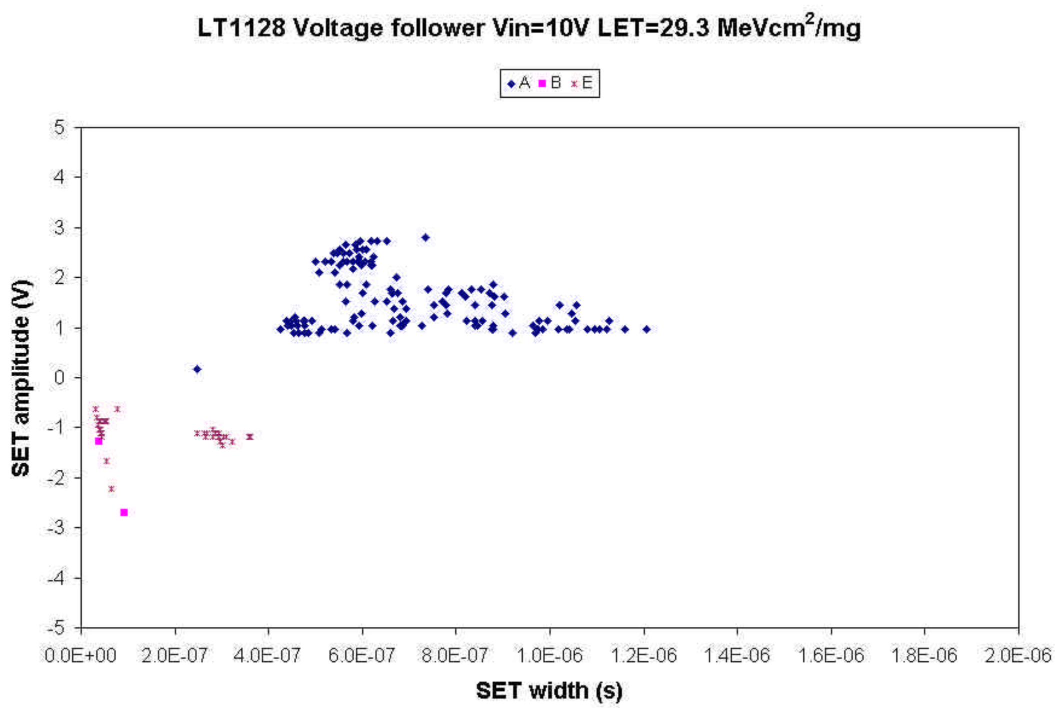
2.0E-06


LT1128 Voltage follower Vin=10V LET=29.3 MeVcm2/mg
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B
E
SET amplitude (V)
SET width (s)
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4
3
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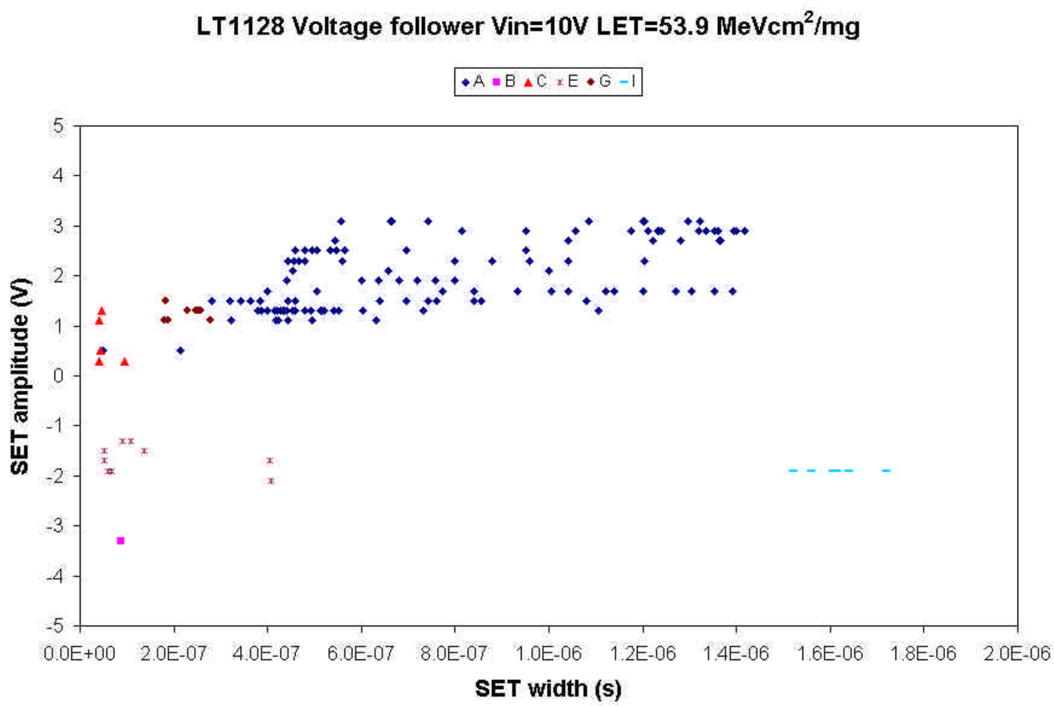
1
0
-1
-2
-3
-4
-5
0.0E+00
2.0E-07
4.0E-07
6.0E-07
8.0E-07
1.0E-06
1.2E-06
1.4E-06
1.6E-06
1.8E-06
2.0E-06


LT1128 Voltage follower Vin=10V LET=53.9 MeVcm2/mg
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SET amplitude (V)
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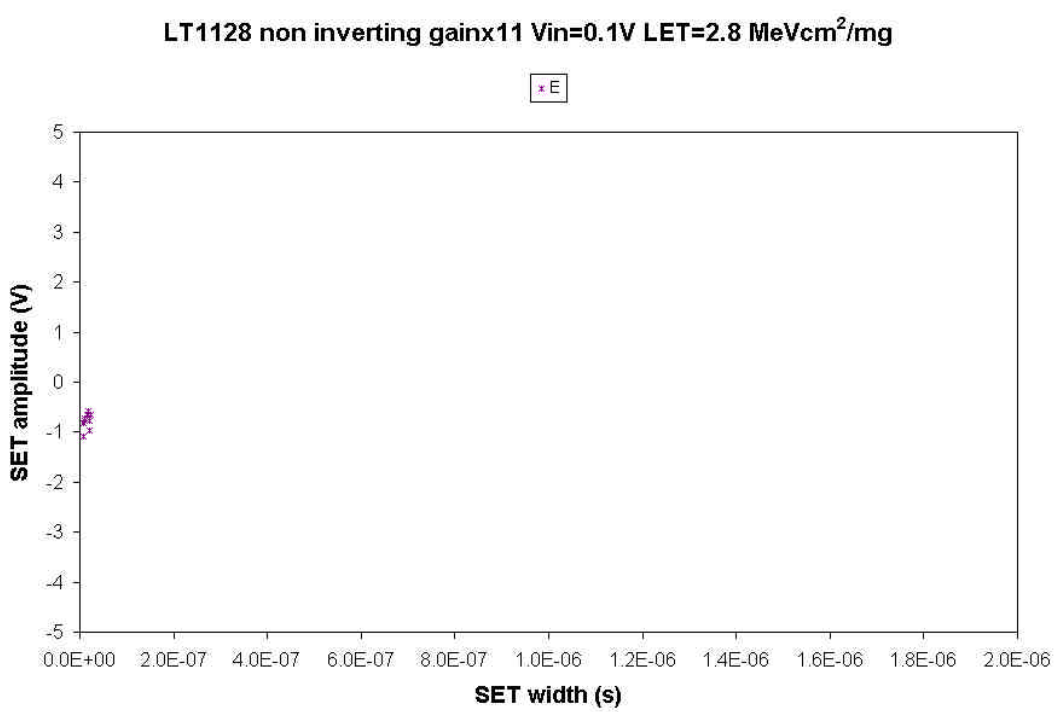
4
3
2
1
0
-1
-2
-3
-4
-5
0.0E+00
2.0E-07
4.0E-07
6.0E-07
8.0E-07
1.0E-06
1.2E-06
1.4E-06
1.6E-06
1.8E-06
2.0E-06
SET width (s)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1
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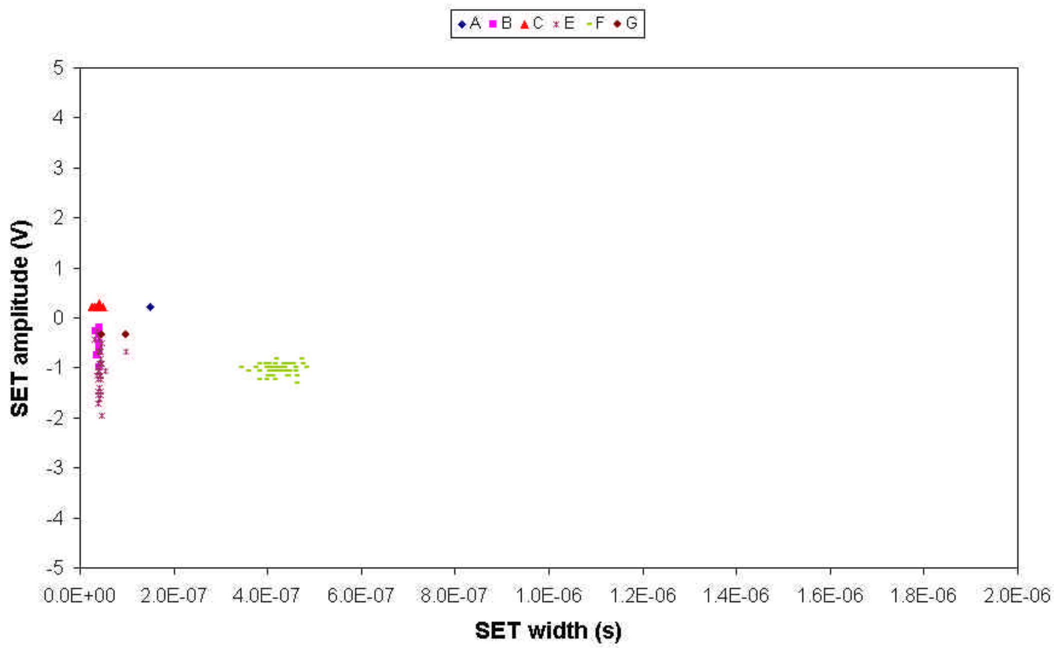
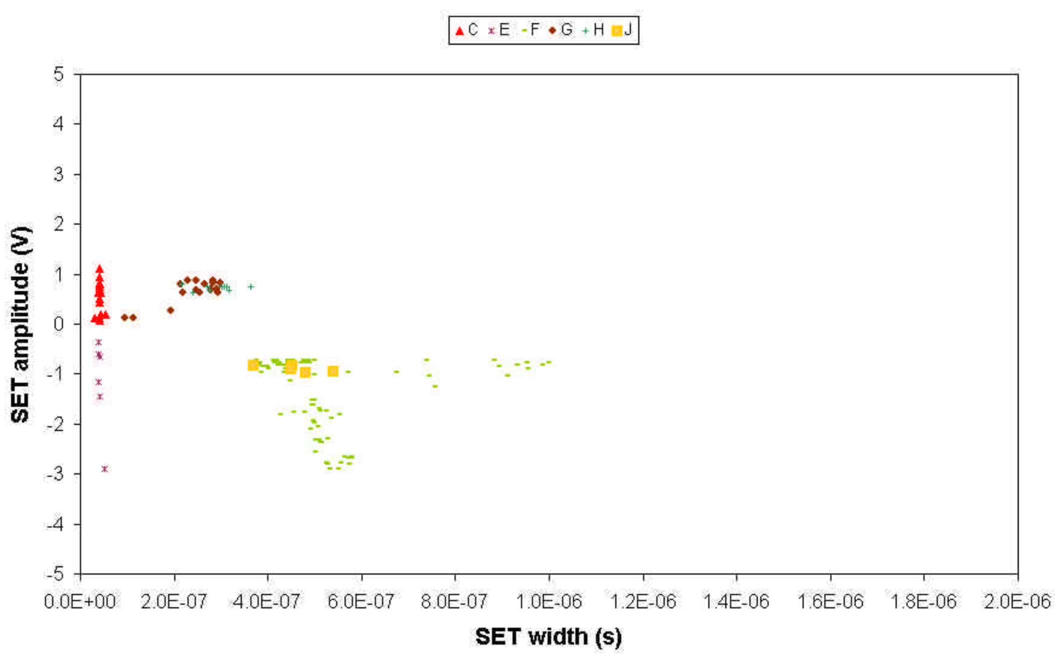
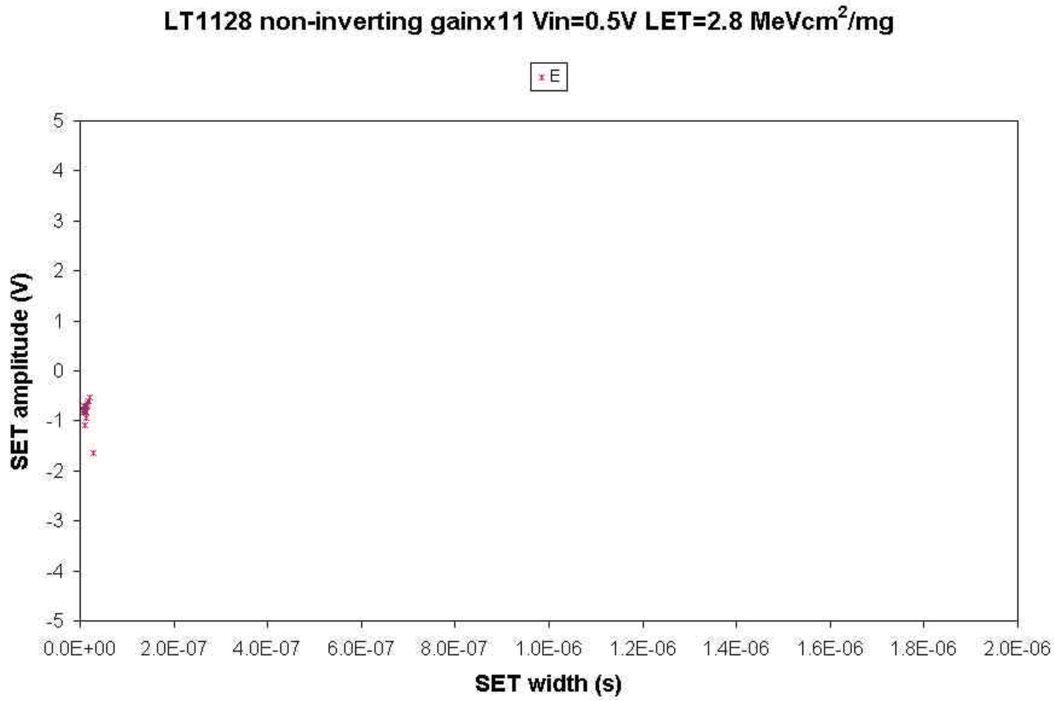
-1
-2
-3
-4
-5
0.0E+00
2.0E-07
4.0E-07
6.0E-07
8.0E-07
1.0E-06
1.2E-06
1.4E-06
1.6E-06
1.8E-06
2.0E-06
SET width (s)

LT1128 non inverting gainx11 Vin=0.1V LET=8.7 MeVcm^2/mg



LT1128 non inverting gainx11 Vin=0.1V LET=29.3 MeVcm^2/mg

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E
SET amplitude (V)
SET width (s)
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4
3
2
1
0
-1
-2
-3
-4
-5
0.0E+00
2.0E-07
4.0E-07
6.0E-07
8.0E-07
1.0E-06
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1.4E-06
1.6E-06
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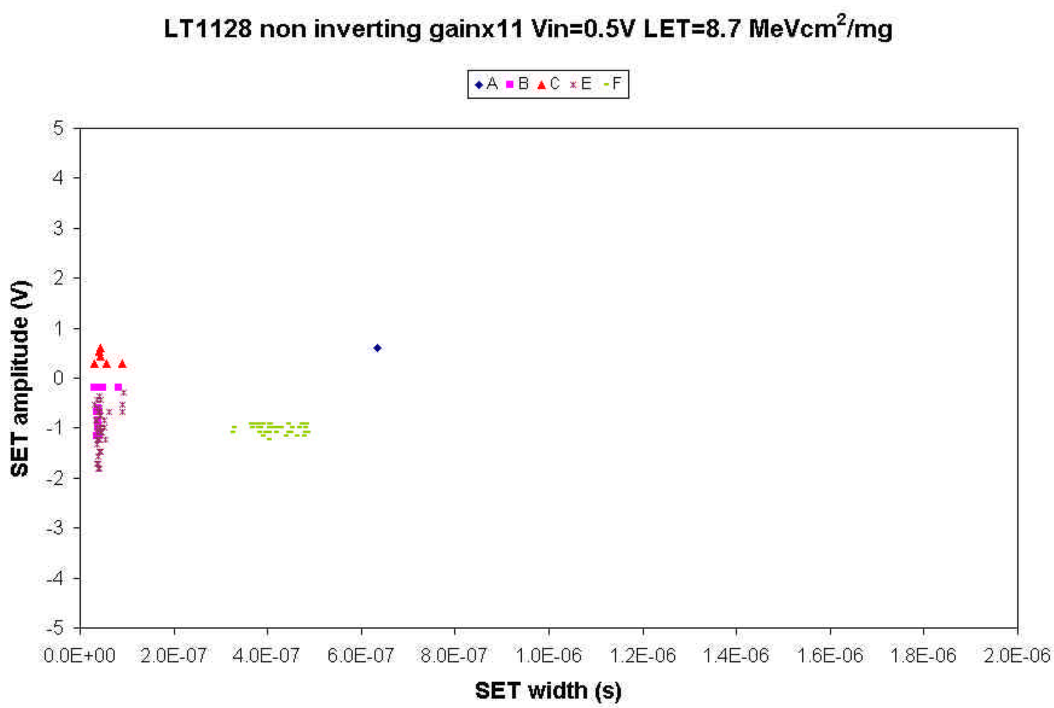
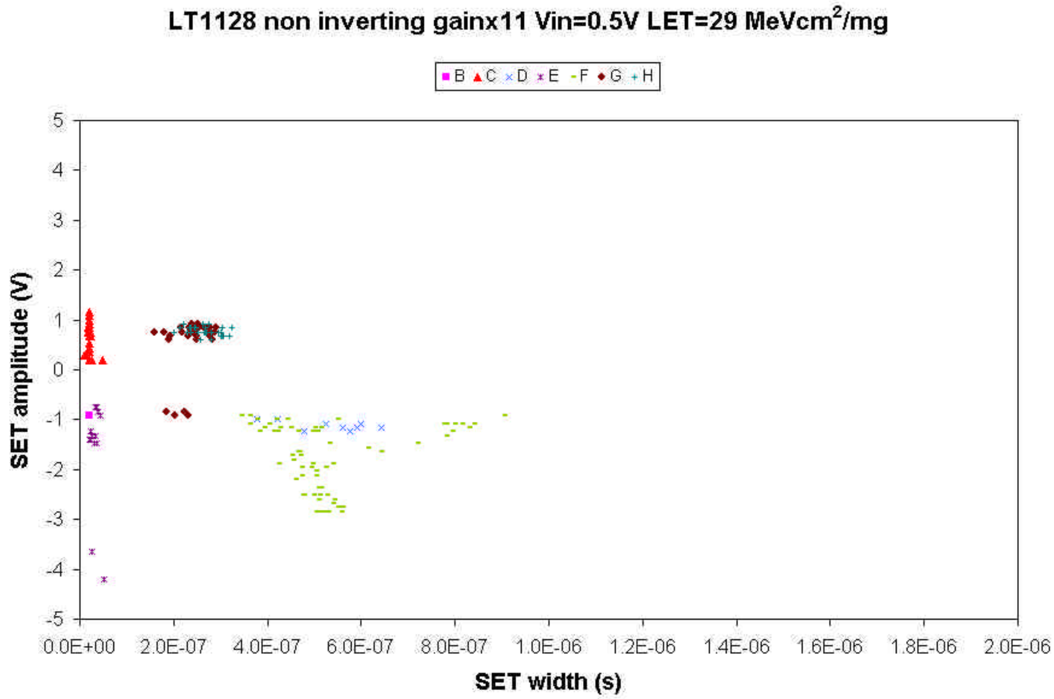
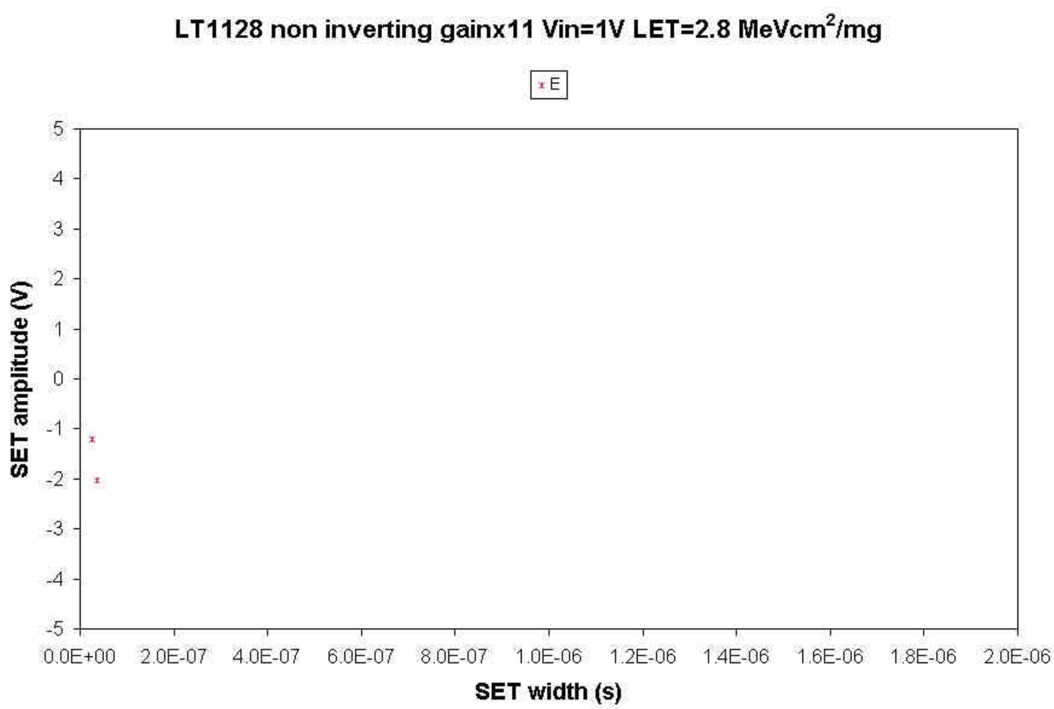
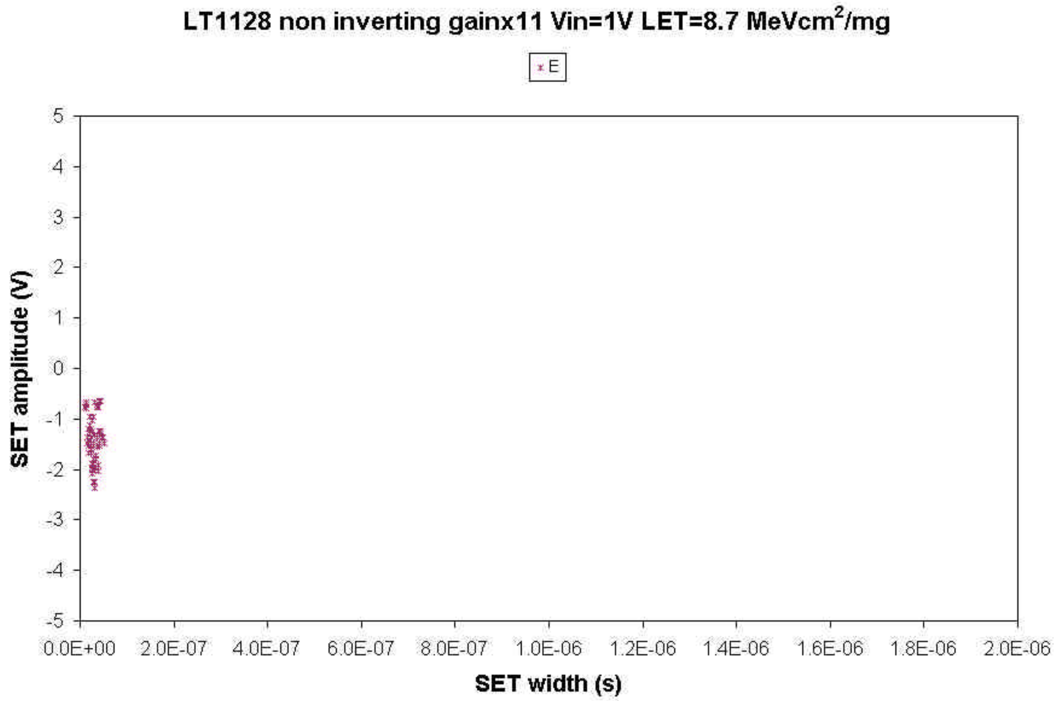

LT1128 non inverting gainx11 Vin=0.5V LET=8.7 MeVcm2/mg
A
B
C
E
F
SET amplitude (V)
SET width (s)
5
4
3
2
1
0
-1
-2
-3
-4
-5
0.0E+00
2.0E-07
4.0E-07
6.0E-07
8.0E-07
1.0E-06
1.2E-06
1.4E-06
1.6E-06
1.8E-06
2.0E-06

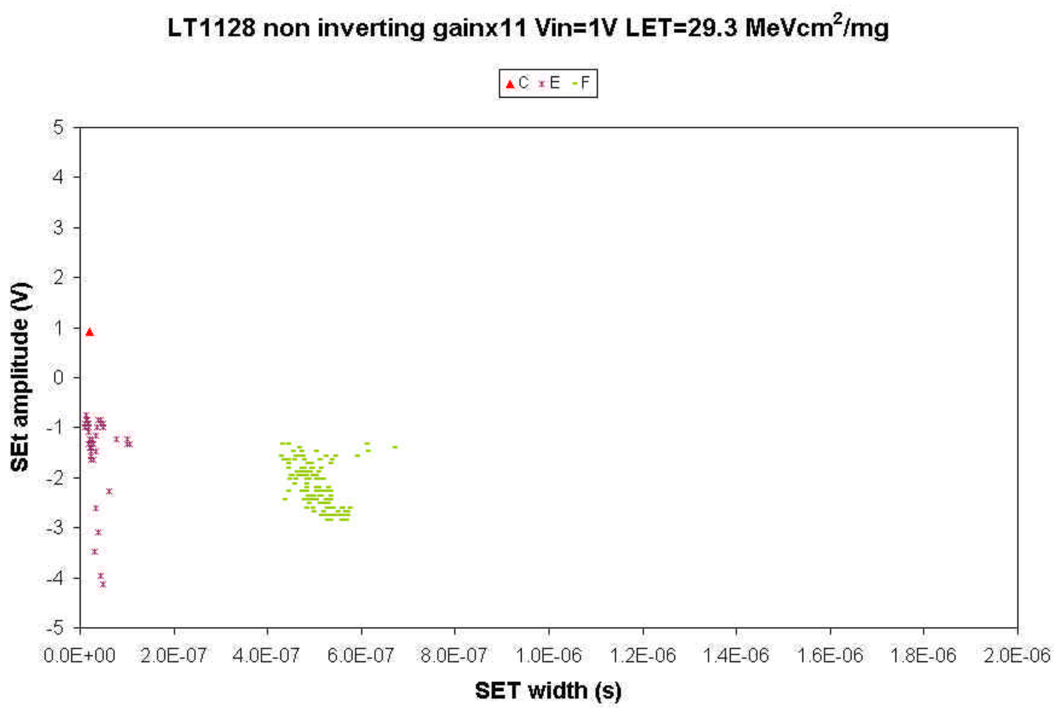


LT1128 non inverting gainx11 Vin=0.5V LET=29 MeVcm2/mg
B C D E F G H
SET amplitude (V)
SET width (s)
5
4
3
2
1
0
-1
-2
-3
-4
-5
0.0E+00
2.0E-07
4.0E-07
6.0E-07
8.0E-07
1.0E-06
1.2E-06
1.4E-06
1.6E-06
1.8E-06
2.0E-06



LT1128 non inverting gainx11 Vin=1V LET=2.8 MeVcm2/mg
E
SET amplitude (V)
SET width (s)
5
4
3
2
1
0
-1
-2
-3
-4
-5
0.0E+00
2.0E-07
4.0E-07
6.0E-07
8.0E-07
1.0E-06
1.2E-06
1.4E-06
1.6E-06
1.8E-06
2.0E-06


LT1128 non inverting gainx11 Vin=1V LET=8.7 MeVcm2/mg
E
SET amplitude (V)
5
4
3
2
1
0
-1
-2
-3
-4
-5
0.0E+00
2.0E-07
4.0E-07
6.0E-07
8.0E-07
1.0E-06
1.2E-06
1.4E-06
1.6E-06
1.8E-06
2.0E-06
SET width (s)


LT1128 non inverting gainx11 Vin=1V LET=29.3 MeVcm2/mg
C
E
F
SEt amplitude (V)
5
4
3
2
1
0
-1
-2
-3
-4
-5
0.0E+00
2.0E-07
4.0E-07
6.0E-07
8.0E-07
1.0E-06
1.2E-06
1.4E-06
1.6E-06
1.8E-06
2.0E-06
SET width (s)